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# Understanding the vulnerability, farming strategies and development pathways of smallholder farming systems in Telangana, India

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ABSTRACT

Climate change projections for the 21st century indicate an increase in the already high number of food-insecure people in India. While considerable research on vulnerability to climate change exists, research about Indian smallholder farming systems as a whole, encompassing farming strategies and development pathways in this context, is limited. Hence, the current study examines the vulnerability of three smallholder farming systems, namely, (i) crop without livestock (CWL), (ii) crop with small ruminants (CSR), and (iii) crop with dairy (CD), in the context of climate change in Telangana, India. A mixed methods approach was used to conduct the research with a sample size of ten households per farming system. We found that households of different farming systems faced differential vulnerability due to variation in perceptions of climate change exposures, access to livelihood capitals, and the farming strategies they chose. The CWL households were highly vulnerable to increased maximum temperature and erratic rainfall, while households that farmed both crop and livestock were more vulnerable to overall reduction in precipitation. Decision-making related to farming strategies was a complex process involving several factors, of which the availability of livelihood capitals, provided by government programs, was the foremost. Due to this, households of the different farming systems pursued divergent farming strategies, leading to varying types of adaptation and climate change resilience. Among the three farming systems, the households in the CWL system had the least access to all livelihood capitals and showed the highest vulnerability as their farm strategies only helped to cope with immediate needs. The households in the CD system had access to all critical livelihood capitals, which facilitated opting for sustainable farming strategies. However, as these households were highly dependent on scarce ground water resources for production, their strategies helped only short-term adaption. The households in the CSR system, despite having access to limited capitals, adopted long-term adaptation strategies which is attributed to them being a pastoral ethnic group. Lastly, despite the existence of an integrated climate change policy, state-level development programs continue to focus more on agricultural intensification than on climate change adaptation. This stimulates farming strategies that are lucrative in the short term but endanger

*Abbreviations:* HH, household; CWL, crop without livestock farming system; CD, crop with dairy farming system; CSR, crop with small ruminants system; SES, socio-ecological system; CPR, common property resource; AESR, agro-ecological subregion.

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farming system resilience to climate change in the long term. We therefore recommend policy makers to give high priority to climate smart development in state development programs, and science-based evaluations of these programs to enable proper climate change adaptation in dryland regions that is inclusive of perspectives of different populations.

## 1. Introduction

The Intergovernmental Panel on Climate Change's Fifth Assessment Report (2014) on adaptation and vulnerability identified water shortage, food shortage, and heat-related mortality as key risks of climate change in Asia. Climate change will affect food security by the middle of the 21st century, with the most significant number of food-insecure people being in South Asian countries, particularly India.

India has large populations of agrarian poor, who depend on natural resources for their livelihood. These populations are already vulnerable and exposed to non-climatic stressors and multi-dimensional inequalities, which makes them even more susceptible to the effects of climate change. Over the past two decades, therefore, considerable research has been carried out in India, covering vulnerability, farmers' adaptation and policies regarding climate change adaptation (Taylor, 2013; Banerjee, 2015; Dubash and Jogesh, 2014; Singh et al., 2014, 2019a; Udmale et al., 2014; Dhanya and Ramachandran, 2016; Maiti et al., 2017; Kuchimanchi et al., 2019). Studies addressing livestock and climate change have also been conducted, mainly reviewing livestock systems, population dynamics, sustainability of livestock systems, and recent trends and future prospects of animal production for developing countries at high aggregation levels (Thornton et al., 2009; Nardone et al., 2010; Thornton, 2010; Alemayehu and Fantahun, 2012; Weindl et al., 2015).

All these studies, however, looked at crop and livestock farming systems in isolation. Research about vulnerability, farming strategies and development pathways at the regional level, encompassing different farming systems and the interaction between them, is limited, in general and in India. Such studies are important since smallholder farming systems, particularly in dryland regions, compete with each other and with other land users for water and land. Often, farmers in dryland regions intensify their crop and livestock production to cope with the conditions and to eke out a living. However, it is still unclear how climate change interacts with the intensification of production and interaction among smallholder farmers (Nardone et al., 2010), and such regional level studies may provide insights.

The aim of the present study was to better understand the vulnerability of three smallholder farming systems that provided consistent agricultural incomes to households (HHs) in the study region, namely, (i) crop without livestock (CWL), (ii) crop with small ruminants (CSR), and (iii) crop with dairy (CD) systems, in the context of climate change along with their farming strategies and development pathways. Here, we focus on climate change vulnerability, coping and adaptation strategies applied by HHs of different farming systems, and the sustainability of their development pathway within the socio-ecological system.

To achieve the above, we use the following theoretical framework and definitions. In line with Gallopın et al. (2006), we first define a socio-ecological system (SES) as a system that includes societal (human) and ecological (biophysical) subsystems in mutual interaction. The SES can be specified for any scale from the local community and its surrounding environment to a larger global system. For vulnerability, we use the concept of Turner et al., (2003): "**vulnerability** rests in a multifaceted socio-ecological system which is exposed to hazards along with dynamic and nonlinear processes operating at different spatiotemporal scales." The most often-cited IPCC definition of vulnerability is the degree to which a system is susceptible to and is unable to cope with adverse effects (of climate change). Turner's framework was chosen because it helps analyze vulnerability and related aspects in a concise form that is inclusive of the larger systemic character of the problem. The framework consists of three broad elements: (i) linkages between human and biophysical conditions and processes operating on the system in question; (ii) perturbations and stressors that emerge from these conditions and processes; and (iii) the SESs of concern in which vulnerability resides, comprising of exposure, sensitivity, and resilience. **Exposure** refers to the nature and degree to which a system experiences environmental or socio-political stress. **Sensitivity** is the degree to which a SES is modified or affected by perturbations (Adger, 2006). **Resilience** is evaluated in terms of the changes a system can undergo due to exposure while continuing to remain within the set of natural or desirable states. Resilience is the dynamic result of the response of an SES to a perturbation, which can be short-term **coping** or long-term adjustment **adaptation**. This adaptation and the associated **adaptive capacity** is the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope (Adger, 2006). Further, to assess the adaptive capacity of rural HHs, we used the Sustainable Livelihoods Framework (DFID, 1999) approach as it advocates that HH level livelihood objectives and strategies are shaped by how people use their asset base, which we refer to as capitals here. The livelihood framework identifies five core asset categories or types of capital, i.e., natural capital, physical capital, financial capital, social capital, and human capital. **Natural capital** is the term used for the natural resource stocks from which resource flows and services useful for livelihoods (e.g., land, water, forests, marine/wild resources, air quality) are derived. **Physical capital** comprises the basic infrastructure and producer goods needed to support livelihoods (e.g., affordable transport; secure shelter and buildings; adequate water supply and sanitation; and clean, affordable energy. **Financial capital** denotes the financial resources that people use to achieve their livelihood objectives such as savings, liquid assets like jewelry, credit, subsidies). **Social capital** refers to the social resources that people use to make livelihoods, such as networks, associations, and cooperatives and memberships in formal/informal associations, which bring in connectedness and cooperation. **Human capital** represents skills, knowledge, ability to labor, and good health.

In this paper, we first describe the socio-economic policy and the environmental contexts and processes operating in the study region (sections 3.1, 3.1.1, and 3.1.2). We then analyze how the HHs in the three farming systems perceive climate change exposure and what sensitivity they face in this coupled human–environment system (sections 3.2, 3.2.1, and 3.2.2). We then explore the different development pathways that the farming systems choose, in terms of coping and adaptation, in sections 3.3.1 and 3.3.2. In the discussion, we reflect upon the drivers behind farm strategy choices, associated vulnerability to climate change, and what it means for the economic and ecological sustainability of the farming systems studied herein.

## 2. Material and methods

### 2.1. Study sample and location

The study was conducted in two watersheds, located in the Rangareddy and Nagarkurnool districts in the state of Telangana, India (Fig. 1). Agro-climatically, both watersheds fall in the Deccan Plateau (Telangana) and Eastern Ghats agro-ecological subregion (AESR) 7.2, which is part of the Southern Plateau and Hill region. AESR 7.2 is broadly characterized by deep loamy and clayey mixed red and black soils with medium to very high available water capacity, and duration of growing seasons ranging from 120 to 150 days. The aridity index of the region is between $0.2 \leq AI < 0.5$ (Rao et al. 2019), and the region is therefore classified as semi-arid. It is also drought-prone as it falls in the scarce rainfall zone, with an annual rainfall of 500–700 mm, which follows a seasonal pattern (Gajbhiye and Mandal, 1983; Manickam et al., 2012).

This study is a follow-up of a previous study, characterizing farming systems in the region (Kuchimanchi et al., 2020a submitted). The region has five farming systems (Table 1). In the present paper, we study the vulnerability to climate change of only three farming systems, i.e., the CWL, CSR, and CD systems because these are the ones providing consistent agricultural income to the HH in the region. The 'landless with livestock' and 'crop-diverse livestock farms' were largely dependent on off-farm income. A two-step sampling process was conducted. First, in the watersheds the village where all farming systems were present, was selected i.e *Thalakondapalle*. Next, within the selected village, 10 HHs per farming system were randomly selected. Within these HHs selected, care was taken that all farm sizes and all caste groups in the region were present - as these could be determinants of vulnerability (Table 2). The farm sizes considered were large farms (>4 ha), medium farms (2–4 ha), small farms (1–2 ha), and marginal farms (up to 1 ha). The caste system in India is a social hierarchical system that has its origins in ancient India. This system, however, has been undergoing transformation since the medieval times including social reforms in modern India (de Zwart, 2000; Bayly, 2001). Nevertheless, the stratification continues to exist in various forms. Currently, according to the government of India classification, castes and ethnic

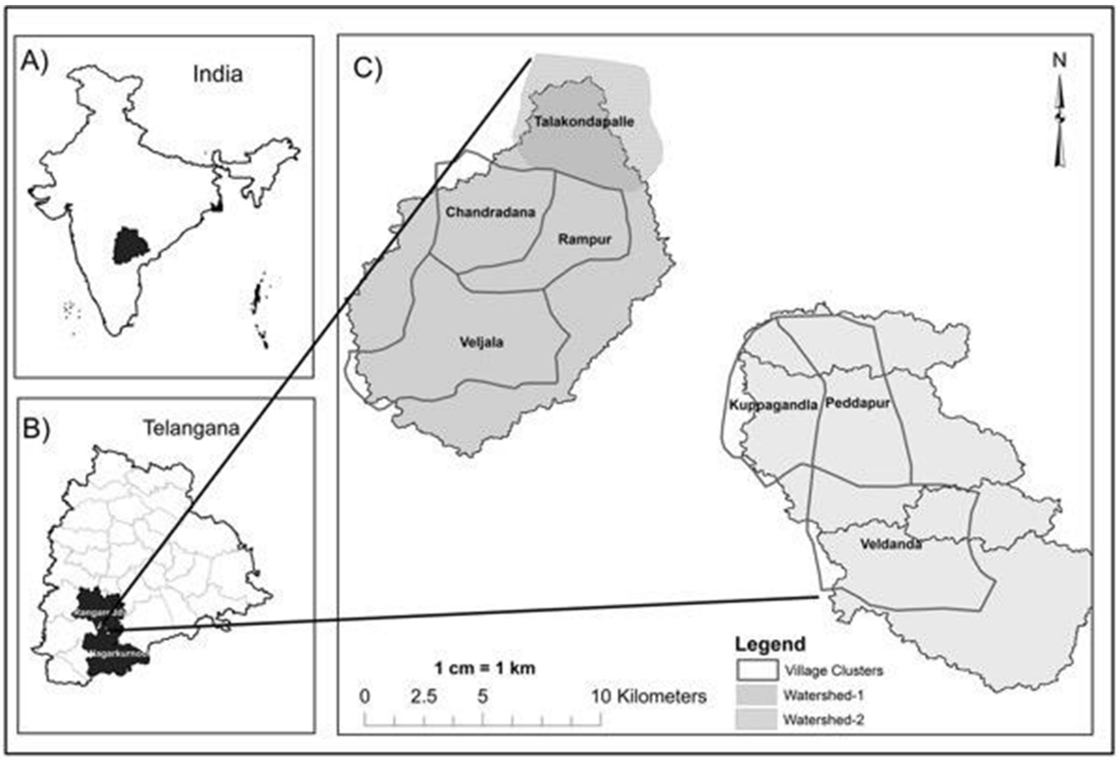


**Fig. 1.** Location map of the study region in India. (A) The study region within the state of Telangana. (B) The two watersheds within which the villages are distributed. (C) The study village Talakondapalle (highlighted in gray). Source: ISRO BHUVAN portal (htpps://bhuvan.nrsc.gov.in/bhuvan_links.php, accessed 2016).

**Table 1**
Distribution of farming systems across the sample watersheds.

| Farming systems | Study villages | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Thalakondapalle | Chandradana | Rampur | Veljala | Peddapur | Kuppagandla | Veldanda | Total HHs |
| Crop without Livestock | 304 | 189 | 147 | 195 | 145 | 165 | 181 | 1326 |
| Crop–Dairy | 232 | 193 | 102 | 115 | 166 | 119 | 136 | 1063 |
| Crop–Small Ruminants | 32 | 16 | 8 | 13 | 34 | 49 | 13 | 165 |
| Landless with Livestock | 22 | 10 | 85 | 16 | 7 | 39 | 9 | 188 |
| Crop–Diverse Livestock | 1 | 1 | 0 | 7 | 6 | 0 | 8 | 23 |

Source: Farming systems characterization data base (Kuchimanchi et al. 2020a submitted).

**Table 2**
Distribution of farm sizes and social groups across farming systems in the study village.

| Farming system | # HHs (%) | Farm size* (%) | Social Groups** (%) |
|---|---|---|---|
| Crop without Livestock | 304 (53.5) | Large farms (8.6)<br>Medium farms (20.1) Small farms (42.8) Marginal farms (28.6) | FC (12.5) BC (45.5) SC (34.2) ST (7.9) |
| Crop–Small Ruminants | 32 (5.6) | Large farms (25.0)<br>Medium farms (50.0) Small farms (18.8) Marginal farms (6.3) | FC(3.1) BC(84.4) SC-(12.5) ST- (0) |
| Crop–Dairy | 232 (40.8) | Large farms (13.4)<br>Medium farms (37.9) Small farms (31.5) Marginal farms (17.2) | FC (6.9) BC (36.2)<br>SC (27.6)<br>ST (29.3) |

* large farms (>4 ha), medium farms (2–4 ha), small farms (1–2 ha), and marginal farms (up to 1 ha).
**FC – Forward caste, BC – Backward Caste, ST – Schedule Tribes, SC – Schedule Caste.
Source: Farming systems characterization data base (Kuchimanchi et al., 2020a submitted).

groups are categorized into 4 main categories i.e., forward castes (FC), backward castes (BC), scheduled castes (SC), and scheduled tribes (ST).

In brief, the CWL farming system is characterized by rainfed crop farming as borewell irrigation was limited post-monsoon season. Hence crop farming is restricted to one agricultural season, due to which these HHs relied more on off-farm income e.g wage labor in government and private construction sites, transportation services and hotels. This system had the highest number of HHs (53.5%) and the majority were small farms (42.8%). The CSR farming system is characterized by both rainfed and irrigated crop farming with sheep or goat rearing. HHs rearing sheep rarely depended on off-farm labour. However, in contrast, HHs rearing goats frequently depended more off-farm labour for additional income. Only 5.6% of the HHs were present in this system, and the majority of them had medium sized farms (50%). The CD farming system is characterized by irrigated crop cultivation and dairying production with high market-orientation. These HHs had guaranteed water resources, better agricultural farm equipment, and were economically self-sufficient. This system had the next highest present of HHs (40.8%), and medium farms were a majority (37.9%)

Further, we found all caste groups were present in all farming systems, owned land and were involved in agriculture in the region (Table 2). Among the groups, the BCs (44%) dominated in presence, followed by SCs (30.3%), STs (16.4%) and FCs (9.3%). The region has two ethic groups, historically specialised in livestock rearing. The first was a traditional livestock-keeping community called the *"Gollas"* classified as BCs (Murty, 1993). The second is the "*Banjaras*," who are STs who were nomadic pastoralists in the past (Ray, 2010) but have now adopted sedentary agriculture.

## 2.2. Methodological framework

A combination of two methods, i.e., a HH survey followed by focus group discussions (FGDs), was used to capture the various facets of vulnerability and farming strategies and pathways associated with the HHs. While the survey helped quantify and measure certain aspects for better justification, the FGD data offered more in-depth knowledge, providing a better understanding of ground realities, particularly of short- and long-term adaptation and farmer strategy choices. The research work was conducted from February to June 2017.

As a first step, we performed a HH survey across the 30 selected HHs using a survey format that covered three principal aspects: (i) the status of livelihood capitals across all relevant HH activities, i.e., crop production, livestock production, and non-farm and forest-dependent activities; (ii) perceptions of climate risks and impacts; and (iii) strategies taken to manage these risks and impacts.

Next, we organized three FGDs, one for each of the three farming systems, and invited two to three members from each HH included in the survey. Therefore, each FGD had around 20–25 participants representing men and women of all age groups. A semi-structured questionnaire was used to guide the discussions in the FGDs. The discussions revolved around perceived climate change exposure, impacts faced, farming strategies adopted, and all factors that influenced the farm strategy choices. Each FGD lasted for 3–4 h, and the discussions were conducted in the local language '*Telugu*', which is also the native- tongue of the first author. Care was taken to organize the FGDs in such a manner that all participants could share their opinions and experiences freely. Key points discussed in the FGDs were documented on charts to spot linkages and identify possible drivers of change. Similarly, climate change exposures and the months perceived as most risky and troublesome were diagrammed to help capture details.

**Table 3**
Farmer perceptions of major climate change exposures in the region.

| | Types of climate change exposures | | | | | | |
|---|---|---|---|---|---|---|---|
| Farming systems (n = 10/system) | Increased maximum temperature | Delayed onset of monsoon | Dry spells | Erratic rainfall | Reduced precipitation | Warmer winters | High-intensity rainfall |
| Crop without livestock | H | H | H | H | M | M | M |
| Crop–small ruminants | H | H | H | L | H | L | L |
| Crop–dairy | H | H | H | L | H | L | L |

Source: Household (HH) survey, n = 10 HHs per farming system.
Note: H: high exposure, score ≥ 8 responses; M: medium exposure, score 5–7 responses; L: low exposure, score < 5 responses.

As a last step, a desk review of the national and state climate-change policy contexts was undertaken. This was done to understand the connections between national-level policies to the human and biophysical (environmental) processes operating within the study region that influence vulnerability.

## 2.3. Data analysis

The survey data were organized in MS Excel based on three principal aspects used in the HH survey, i.e., (i) the status of livelihood capitals, (ii) perceptions of climate risks and impacts; and (iii) strategies taken to manage these risks and impacts to identify trends and patterns. We also quantified the number of responses per farming system to determine high exposure (≥8 responses), medium exposure (5–7 responses), and low- exposure (<5 responses) on the perception of climate exposure (Table 2). A similar method was used to determine the level of impact of the identified climate change exposure on the different farming systems (Table 3), where ≥8 responses meant high impact, 5–7 responses meant medium impact, and <5 responses meant low impact. On the same lines, the status of the livelihood capitals (Table 4) was also assessed as high, medium, and low access or ownership based on the responses. High indicated a score above 8 responses, showing that the majority of farmers owned or had access to the particular capitals, medium was a score between 5 and 7 responses, and low was a score of <5 responses. Finally, the adoption of farming strategies (Table 5) was also scored based on number of responses, where ≥8 responses indicates high adoption, 5–7 responses indicates medium adoption, and <5 is low adoption. These data were later corroborated with the FGD data to develop consistent case stories of each farming system related to their vulnerability and adaptation.

# 3. Results

## 3.1. The context

### 3.1.1. Socio-economic and policy context

Agriculture, with its allied sectors, is the largest source of livelihood in India. Seventy percent of India's rural HHs depend primarily on agriculture for their livelihood, with 82% of farmers being small and marginal. While Indian agriculture has achieved self-sufficiency in grain production, it has become intensive, and serious sustainability issues such as increased stress on the country's water resources, desertification, and land degradation have emerged (FAO, 2019). To sustain India's rapid economic growth a large number of rural development policies and programs exist which address multiple objectives to improve social and economic standards of rural HHs along with natural resource management. Among these the Government of India formulated the National Action Plan on Climate Change (NAPCC) in 2008, focused on climate change adaptation. The NAPCC encompasses eight national missions, among which the National Water Mission (NWM), the National Mission for Sustainable Agriculture (NMSA), and the State Level Action Plan on Climate Change (SAPCC) are of relevance to this study. However, an exploration of these policies indicates that, though the missions are integrated and climate-centric at the central level, the interventions at state – level are aimed at livelihood and regional economic development and not on climate change adaptation. For example, the Rainfed Area Development (https://nmsa.dac.gov.in/Default.aspx) a component of the NMSA is formulated in a 'watershed plus' framework. It reaches rural HHs through national-level umbrella programs[1] that focus on holistic agriculture development, allied sectors and water management and are customised at state-level. However, we find that the interventions in relation to crop-livestock production do not reflect climate smart measures and tend to promote green and white revolution technologies or are intensification-oriented. We also find minimal adoption of interventions advocated by the Central Research Institute for Dryland Agriculture[2] or the SAPCC of Telangana. This situation may possibly be due to political dynamics and lack of collaboration among policy makers and research which is negatively influencing climate change adaptation at local-level. This is because the livelihood capitals available at the local level come through these programs and their associated schemes and subsidies. These tend to influence farm strategies and adaptation pathways of rural HHs that are not necessarily climate adaptive.

[1] RKVY: https://rkvy.nic.in/ , PMKSY: https://pmksy.gov.in/AboutPMKSY.aspx
[2] the lead institute and national nodal point for the National Innovations in Climate Resilient Agriculture

**Table 4**
Level of impact of climate change exposure on different farming system.

| Climate change impacts | CWL system farmers | CSR system farmers | CD system farmers |
|---|---|---|---|
| Decrease in crop yields | H | M | H |
| Increase in disease and pests in crops | H | L | M |
| Increase in crop losses | H | L | M |
| Inability to grow certain crops | – | – | L |
| Increase in soil heating | H | L | M |
| Decrease in vegetation in common property resources | M | H | H |
| Decrease in crop residues | – | H | M |
| Increase in diseases in animals | – | H | L |
| Increase in heat stress in cattle | – | – | M |
| Decrease in groundwater levels | H | L | H |
| Decrease in surface water bodies | – | H | – |
| Increase in health issues in humans | M | – | – |

Source: Household survey.
Note: H: high impact, score ≥ 8 responses; M: medium impact, score 5–7 responses; L: low impact, score < 5 responses; CWL, crop without livestock; CSR, crop with small ruminants; CD, crop with dairy.

### *3.1.2. Environmental context*

Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5 °C and increase further with 2 °C (IPCC, 2018). Chapter 7 of the IPCC AR5 WG II states that there is a high probability that developing countries will be negatively affected by climate change, particularly food security. This is also predicted for India, where 69% of the land area is dryland (arid, semi-arid, and dry sub-humid). India is among the most drought-prone regions of the world (Ajai et al., 2009; Banerjee, 2015), and the above mentioned transitions towards intensive agriculture continue to progress (Amjath-Babu and Kaechele 2015; Behera et al. 2016; Gathorne-Hardy 2016; Kuchimanchi et al., 2020b submitted). Such transitions to intensification of land and water use, according to IPCC's Climate change and Land report (2019) enhance land degradation, water scarcity and food insecurity in drylands. The World Bank report (2012) "Turn Down the Heat" indicates that India is already facing water stress conditions, in the form of droughts and floods, in many parts of the country. In the future, unusual and unprecedented spells of hot weather are expected to occur more frequently, whereas India's summer monsoon is expected to be highly unpredictable, with frequent droughts in some parts of the country (IPCC, 2018, Rao et al., 2019). These climate change phenomena will further impact agriculture, with already falling water tables. Moreover, Reddy et al. (2014) stated that the projected climate change for southern Telangana (the study region) coincides with increasing crop water requirements. Hence, the future context of agriculture portends higher water requirements, less reliable precipitation, and intensified groundwater exploitation.

## *3.2. Smallholder farming systems and vulnerability to climate change*

### *3.2.1. Farming systems and perceived exposure to climate change in the region*

Both FGDs and the HH survey revealed that farmers of all three farming systems recognized a change in climate since the year 2000. The main climate change exposures, perceived by the respondents (in decreasing order of frequency) were increased maximum temperature, erratic rainfall, reduced precipitation, increased frequency and length of dry spells, delayed onset of monsoon, warmer winters, and increased frequency of high-intensity rainfall (Table 3).

A high number of farmers (males as well as females) from all farming systems perceived increased maximum temperature, delayed onset of monsoon, and dry spells as climate change exposures. CWL farmers highlighted erratic rainfall most frequently, whereas CSR and CD farmers noted reduced precipitation most frequently. Warmer winters and high-intensity rainfall were mentioned by less than half of the farmers. Respondents further added that at times, these climate change exposures occurred simultaneously.

### *3.2.2. Farming systems and perceived sensitivity to climate change in the region*

The major effects of climate change exposure identified by farmers are presented in Table 4. The different climate change exposures had different levels of impact on the different farming systems. For example, CWL farmers, who only produced crops, reported decreasing crop yields, increasing disease and pest attacks, crop losses, heating up of soil, and decreasing groundwater levels as the main effects of climate change that impacted them greatly. In this aspect men spoke about overall income loss, while women referred to negative impacts on food security and on other basic HH needs. The CWL farmers further mentioned a medium impact on human health due to the increase in maximum temperature and warmer winters. The increase in maximum temperature hampered the ability to work for extended hours, especially for women as they are the main work force in vegetable or cash crop cultivation. Many respondents noted that in this situation they were not able to offset income loss through more alternative wage work or hiring of farm machinery. Higher pest and disease incidence, an effect of erratic rainfall, also increased production costs, e.g. investments in pesticides and fertilizers. Further, while groundwater depletion is an existing problem in the region, changes in climate such as reduced precipitation accentuate the issue. Thus, inadequate groundwater limited the area under crop production, which reduced crop residue availability and ultimately affected livestock rearing—all of which contributed to loss of income and food security, especially for women and children.

For CSR farmers, the major effects of climate change reported were increased incidence of animal diseases, reduced availability of

**Table 5**
Farming systems and their livelihood capital status.

| Livelihood capital indicators | Status of livelihood capitals according to farming system | | |
|---|---|---|---|
| | CWL system farmers (n = 10) | CSR system farmers (n = 10) | CD system farmers (n = 10) |
| **Natural capital indicators** | | | |
| **Land use pattern** | | | |
| Irrigated lands | L | M | H |
| Leased lands | L | H | M |
| Seasonal fallow lands | H | H | L |
| **Cropping pattern** | | | |
| Cash crops only | H | M | L |
| Cash crops with crop residues & green fodder | NA | L | H |
| **Livestock resources** | | | |
| Mixed livestock | NA | L | L |
| Specialized livestock farming | NA | H | H |
| **Natural water resources for livestock** | | | |
| Natural water bodies, seasonal | NA | M | NA |
| **Forest resources** | | | |
| Access to fodder & non-timber forest produce | L | L | NA |
| **Fodder resources** | | | |
| Common property resources | – | L | NA |
| Grazing on leased land | NA | H | M |
| Purchase fodder from markets & other farmers | NA | M | H |
| Reduce crop production and use land for grazing | NA | M | H |
| Grow green fodder | NA | L | H |
| **Physical capital indicators** | | | |
| **Irrigation infrastructure** | | | |
| Own borewells, functionality | L | M | H |
| Lease borewells | nil | M | L |
| Own water-efficient system | nil | nil | L |
| **Agriculture infrastructure** | | | |
| Manual implements | H | M | – |
| Bullocks (rented) | M | M | L |
| Farm machinery (rented) | H | H | L |
| Post-harvest structures | L | L | M |
| **Financial capital indicators** | | | |
| Crop & livestock insurance | M | H | L |
| Crop & livestock subsidies | M | H | M |
| Formal and informal credit | H | M | H |
| Investments in animal health | NA | H | M |
| Wage labor | H | L | NA |
| **Social capital indicators** | | | |
| Membership in farmers' groups/animal breeders' societies/women's self-help groups | M | L | M |
| **Human capital indicators** | | | |
| **Knowledge on sustainable crop–livestock management** | | | |
| Knowledge levels | L | – | M |
| Have knowledge, do not practice | – | H | L |
| Have knowledge, limited practice | L | L | H |
| Access to climate information services | L | L | H |
| Presence of traditional knowledge | L | H | L |
| **Alternate skill sets/farm/off-farm** | | | |
| Only farm-based skills | H | H | H |
| Have both farm and off-farm skills | H | L | L |
| Traditional occupational skills | L | H | L |
| **Education** | | | |
| School drop-outs | H | H | L |
| Completed schooling | L | L | M |
| Higher education | L | L | M |

Note: H: high access, score $\geq$ 8 responses; M: medium access, score 5–7 responses; L: low access, score $<$ 5 responses; CWL, crop without livestock; CSR, crop with small ruminants; CD, crop with dairy.

crop residues, decreased availability of surface water bodies, and reduced vegetation in common property resources (CPRs). While these problems relate to non-climatic factors, climate change exposure compounded the impacts. According to the farmers in this CSR system, these climate change effects impacted small ruminant production considerably because the once zero-to-low input production system had to be transformed into a high-input system. Both men and women noted that they now have longer grazing hours and higher production costs due increased expenses for animal health care, besides the need to purchase fodder lease lands and borewells for grazing and watering, respectively. However, for women and poor HHs who cannot afford these additional investments, reduced their livestock and became deprived from critical nutrients and income.

CD farmers listed out many effects but underscored only three that caused most distress, namely, groundwater depletion, lowered crop yields, and decreasing vegetation in CPRs. They reported that over time these climate change effects forced them to increase their investments in agricultural, with no guarantee for good returns. They further added that climate change has made it difficult to grow certain crops, e.g., rice and sorghum. This forced them to produce cash crops such as cotton and maize, which provide less food grains and crop residues for livestock.

### 3.3. Farm livelihood capitals and strategies

Within the above context, the current section describes (i) how farmers belonging to the three farming systems have access to livelihood capitals and (ii) the different strategies that make up the farming HH's "resilience."

#### 3.3.1. Three farming systems and their access to livelihood capitals

Table 5 presents the status of livelihood capitals for the three farming systems in the region, as emerging from the HH survey. The scoring revealed that farmers in the CWL system had the lowest ownership of key natural capital indicators, i.e., land, livestock ownership, access to water, irrigated land, and forest and fodder resources for livestock. The majority had to leave a considerable part of their crop land seasonally fallow, as they had limited capacity to lease additional agricultural land. All the CWL farmers cultivated exclusively cash crops and used solely inorganic inputs as they did not own livestock. Factors that made rearing livestock difficult were reducing CPRs, inadequate water resources and state-imposed ban on forest grazing. CWL HHs also had the least physical capital, particularly access and ownership to irrigation and agricultural infrastructure. They owned the lowest number of borewells, which were merely seasonally functional. They predominately owned manual implements and rented farm machinery and bullocks, thereby incurring relatively high crop production costs. Regarding financial capital, the CWL HHs were most dependent on wage labor and crop insurances. Interestingly, the majority of the CWL HHs were members of farmer producer organizations, informal farmers' groups, and women self-help groups (WSHGs) i.e., social capital. With respect to human capital, most of the CWL farmers had very limited knowledge of sustainable farm management and were the least educated. However, the majority had multiple skill sets, i.e., farm-, off-farm-, and traditional occupational skills, at the HH level.

Among the CSR farmers, some owned irrigated land, while others did not. Like the CWL farmers, these farmers also left their croplands fallow in one or more agricultural seasons, particularly in bad rainfall years. With regard to cropping patterns, these farmers cultivated cash crops that produced crop residues, such as maize or groundnut. They used both inorganic fertilizers as livestock manure for crop production as they owned livestock. Shrinking CPRs and denied access to forest lands for grazing impacted the CSR farmers the most, and hence, the majority leased croplands for their small ruminants. Some purchased fodder from markets when needed. Due to reduced precipitation and dried up surface water, CSR farmers faced limited availability of water for livestock. The CSR farmers themselves owned very few borewells, which were mostly seasonally functional, but all were able to lease borewells to overcome the problem of water scarcity. With regard to financial capital, CSR farmers reported the highest dependence on crop/livestock insurance and subsidies (e.g., investment support schemes, seed and fertilizer inputs). Some of them also indicated dependence on wage work but only under difficult circumstances or when in need of extra finances. Regarding human capital, a majority of the CSR farmers had knowledge of sustainable crop–livestock farming practices but did not practice it. Almost all farmers reported to have traditional knowledge of sheep rearing.

The CD farmers had the best access to all livelihood capitals. With regard to natural and physical capitals, their lands were fully irrigated. They owned multiple borewells that were functional throughout the year, resulting in better incomes. This enabled them to grow green fodder and also purchase fodder and crop residues from markets. They also leased lesser land for grazing than the CSR farmers. The agricultural infrastructure for crop production comprised a high ownership of farm machinery and the application of sustainable mixes of inorganic fertilizers and livestock manure. The CD farmers were also the sole farmers using water-efficient systems. As for human capital: the majority of CD farmers had high levels of education, knowledge of sustainable crop–livestock management, and good access to climate information services.

We found that all farming systems had HHs from all social groups and farm sizes. However, SCs and HHs with small farms had a higher prevalence in the CWL system, in which HHs had the lowest livelihood capitals. The CD and CSR systems were dominated by BCs and HHs with medium size farms and had more access to livelihood capitals. This included the STs; though lowest in caste hierarchy, they had a higher prevalence in the CD system. Similar was the case with BCs, who had highest presence in the CSR system (Table 2). Hence, social groups with ethnic identities linked to livestock rearing (the STs – *Banjaras* and the BCs – *Gollas*) seemed to fare better as shown by their relatively good access to livelihood capitals.

With respect to women, there was a mixed impact. On one side, having higher social capital increased their access to livelihood capitals, providing loans, livestock assets, and technologies through the government WSHGs program. However, climate change impacts on crop-livestock production (Table 4) that resulted in loss of incomes made loan repayment difficult, especially for the WSHGs formed by lower caste women as compared to the FC women.

#### 3.3.2. Farming systems and their farming strategies

CWL farmers reported that their choice of cash crop production (notably cotton) over food crops had been an unavoidable strategy (Table 5). Cash crops had higher market values and guaranteed a better income to cover immediate needs than food crops. It enabled them to cope with decreasing land sizes. For example, CWL farmers mentioned that cotton production saved time and enabled them to take up other livelihood activities. The cotton crop required limited field work and provided reasonable yields even under rainfed/less irrigated conditions. Some CWL farmers noted that they tried to simultaneously grow cash and food crops but discontinued it as the income earned was insufficient. Furthermore, as climate change exposure led to variable yields, farmers became highly dependent on intermediaries, willing to buy low-quality and low quantities of produce. As the CWL HHs now grew only cash crops, they became highly reliant on the markets and the public food distribution system for their food needs.

To enhance crop productivity, CWL farmers increasingly used inorganic inputs. Most sampled farmers knew that high use of inorganic fertilizers was not sustainable, but they claimed they had no other option as they lacked livestock and the means to purchase manure. They did, however, apply farm mechanization, using tractors and crop harvesters. This increased production costs, but they noted that it enabled HHs to work extended hours under increasingly high temperatures. To pay the high production costs, CWL farmers increasingly resorted to government subsidies, and formal and informal credit. As crop production became troublesome, many CLW farmers started to lease out their fallow croplands as a source of revenue. When in difficult circumstances, these farmers reported to sell assets as one of their main strategies to cope and manage loan cycles. Respondents noted this was an effective strategy to overcome temporary risks but marginalized them over time. As crop production had become highly unpredictable, increased engagement with wage work became a crucial livelihood strategy. However, to their dissatisfaction, high daytime temperatures impeded more wage work, causing health issues. Furthermore, as agricultural work opportunities were reported to be inadequate, HHs also resorted to migration. Lastly, though the CWL HHs had the highest social capital it did not increase their networking or knowledge levels. Low education levels (human capital) compounded by low financial capital rendered it ineffective.

Like CWL farmers, CSR farmers also grew cash crops but opted more frequently for maize and groundnut crops as it required lower investments, was better for the soil quality, and provided crop residues as fodder for livestock. Their use of inorganic fertilizers was relatively low as they owned livestock. Similar to the CWL farmers, adoption of farm mechanization was a well-known strategy to manage both crop and small ruminant farming. CSR farmers showed high concern for their small ruminants. To cope with reduced CPRs for grazing and fodder scarcity, CSR farmers leased croplands and bought crop residues from other farmers and markets. In times of water shortage and unpredictable or delayed monsoons they also deliberately left croplands fallow for more grazing area. To ensure drinking water for their livestock, CSR farmers chose not to invest in new boreholes, as the success rate to get a functional borewell was low, and they rather leased borewells from other farmers. This, however, made them dependent on the willingness of other farmers to share water with them. CSR farmers reported heavily investing in animal health care because climate change exposure led to many health issues. They complained, however, that animal health services hardly catered to small ruminants. For animal sales, CSR farmers in this region had always relied on middlemen and still did. Further, like the CWL farmers, CSR farmers also highly depended on government subsidies and insurances, and they obtained their food from the markets and the public food distribution system.

CD farmers displayed rather distinctive farming strategies. They cultivated cash crops that simultaneously provided crop residues for feed, and they even grew food crops. This reduced their dependence on the public food distribution system. CD farmers owned some farm machinery and demonstrated the highest level of farm mechanization. They claimed it was an effective strategy to manage the labor shortages and increasing wage labor costs experienced in the region. They, however, invested heavily in new borewells, though they were aware that continuous digging of new borewells was not a sustainable option. Hence, structural water shortage stimulated them to adopt water-efficient systems, e.g., drip irrigation, and many respondents noted that they reduced the cropping area to save water for their dairy livestock, as the latter guaranteed a more stable income. CD farmers forwarded various strategies to manage their livestock and fodder scarcity, such as buying locally bred exotic cattle; relocating cattle to areas with more fodder and water resources; and the cultivation of fodder varieties with lower water requirements, such as fodder sorghum. CD farmers also highly invest in livestock infrastructure, e.g., water troughs and storage tanks, chaff cutters, and cattle sheds. They are less dependent on middlemen as they have access to town and city markets.

## 4. Discussion

### *4.1. Climate change vulnerability, farming strategies, and HH resilience connect*

The frequently cited definition of vulnerability is the degree to which a system is susceptible to and is unable to cope with adverse effects of climate change (Adger, 2006). In this study, we found that farmers from different farming systems faced differential vulnerability owing to differences in perceptions of climate change exposure, experienced sensitivity, and coping or adaptation strategies (Amamou et al., 2018; Mubiru et al., 2018). HHs in all three farming systems reported a change in maximum temperature, delayed onset of monsoon, and dry spells due to higher intensity of the exposure, but while CWL farmers highlighted the impact of erratic rainfall, warmer winters, and high-intensity rainfall events, CSR and CD farmers rather underscored reduced precipitation as the prime climate risk. The difference in perceptions between farming systems were highly linked to their contrasting farming focus and related sensitivity. For example, CWL farmers mainly depended on crop farming; hence, their production was highly sensitive to events such as erratic rainfall, warmer winters, and high-intensity rainfall events. CSR and CD farming systems, on the other hand, relied more on livestock and consequently were less sensitive to the weather events mentioned by the CWL HHs. However, CSR and CD farming systems needed good overall precipitation to ensure adequate grazing and water resources for their livestock.

The study also revealed that decision making in farming and the choice of a certain farm strategy is a complex process. Factors such as differential sensitivity to climate change, access to livelihood capitals, and market forces like distinctive market prices between cash and food crops or demand for certain animal products all influenced how HHs of different systems chose their farming strategies (Singh et al., 2016; Li et al., 2016; Tripathi and Mishra, 2017; Amamou et al., 2018; Mubiru et al., 2018). Though exposure to climate change was felt by HHs in the region the study showed that the vulnerability of HHs mainly depended on the lack of certain HH livelihood capitals which were provided by ongoing national level programs. The main capitals were the availability of water resources, ownership of livestock, access to grazing lands (CPRs and post-harvest crop lands), adequate financial capital both in the form of investment flow and subsidies, higher education, and knowledge of sustainable agricultural practices.

The CWL HHs had no or limited access to all these essential capitals and hence showed the highest vulnerability. To cope, they chose to grow high-value cash crops over food crops in small land holdings. The lack of CPRs inhibited them to keep livestock; hence, they depended on inorganic inputs, off-farm jobs, or sold assets for survival. Low income prevented them from leasing lands and water resources. Finally, low education levels limited their networking abilities for accessing suitable subsidies or finances, further limiting their adaptation capacity. In all, the strategies opted for helped them to cope and meet their immediate needs but reduced their long-term resilience.

The CD HHs had access to all critical capitals mentioned above. However, the high human capital, i.e., relatively high level of education and extensive network contacts, enabled them to get the necessary finance, subsidies, and relevant knowledge. Possessing high human capital facilitated the HHs to engage in more sustainable farming strategies such as the adoption of water-efficient systems, use of climate information services, shift to alternative crop varieties that used less water, improved livestock, animal healthcare, and improved feed management (Table 5). These strategies helped CD HHs to adapt and prosper in the short term. However, there exists a long-term risk of the borewells becoming defunct as water is a non-renewable resource.

The CSR HHs presented a different story as they belonged to a specific category (*Gollas*), with a long history and strong identity as traditional livestock keepers. This identity, traditional knowledge, and high appreciation of livestock farming made them opt for different farming strategies compared to CWL and CD HHs. They chose to invest in livestock health, selected cash crops that provided crop residues, and leased grazing areas and borewells instead of digging new ones. These strategies made them less sensitive to climate change exposure and other non-climatic stressors in the region and seemed an effective long-term adaptation strategy.

From the social perspective, the SCs and HHs with small farms were the most vulnerable as they had lowest access to capitals. Their presence was also highest in the CWL system which is the most vulnerable among all three farming systems (Table 2). Further, the STs

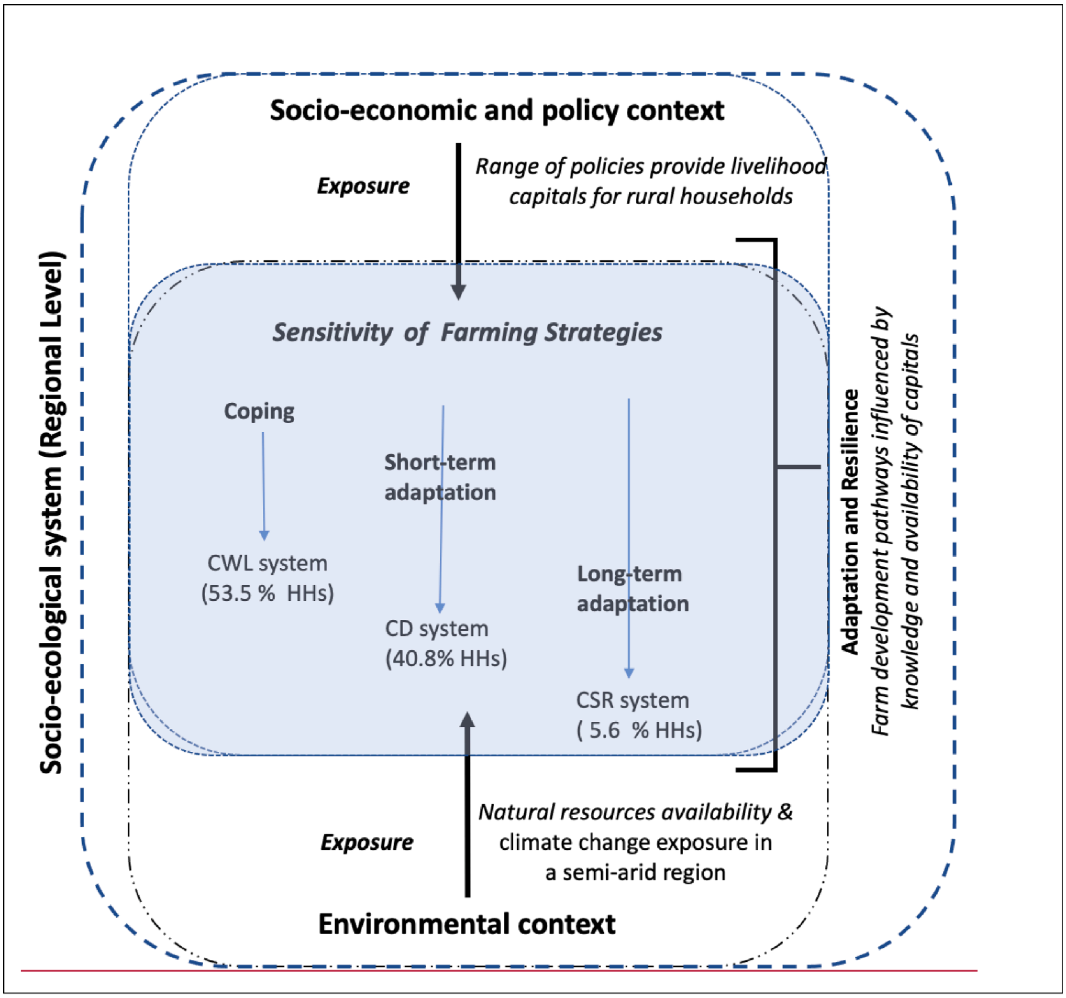


**Fig. 2.** Components of a social-ecological system that influence farm development pathways, adaptation and resilience.

(*Banjaras*) and the BCs (*Gollas*) had a high human capital related to livestock farming, which made them less vulnerable. Ethnic identity and traditional knowledge played a key role for HH resilience for both these groups (Kuchimanchi et al., 2019). For the STs it helped access necessary capitals and attain better social status in comparison to the SCs. The BCs (*Gollas*) however, were far more resilient as they seemed to just modify their farm strategies while keeping their original occupation unlike the STs who transitioned from nomadic pastoralists to settled dairy farmers.

Concerning gender, while both men and women had similar perceptions of climate change exposure, they were impacted differently due to their gender-specific farm and domestic responsibilities (Morchain et al., 2015; Rao et al., 2019). We found existing difficulties women face in farming are compounded by climate exposure. First, the loss of income and increased indebtedness due to impacts of climate change on farm production drives men to migrate for work opportunities. This undermines the well-being of women in various ways (Rao et al., 2019) and also leads to the feminization of farm work (Vepa, 2005; Pattnaik et al., 2017). Longer working hours under maximum day time temperatures is likely to translate into more heat related health implications for women. Similarly, decreasing availability and loss of vegetation in CPRs, coupled with reduced crop residues have higher implications for women, since prolonged grazing hours interfere with domestic responsibilities while social norms prevent them to invest in fodder or lease land. Lastly, though WSHGs created opportunities for livelihood diversification, climate change impacts on farm production (Table 5) increase the risk in loan repayment, especially for poor HHs. These factors together.

We thus conclude that the resilience of HHs in the study region depended on the concomitant availability of several livelihood capitals. We found that human capital, in the form of higher education levels and networking abilities helped CD HHs to articulate their adaptation pathways. Traditional knowledge and culture played a critical role in defining the adaptation strategy for the BC and ST HHs in the CSR and CD systems respectively and is possibly the reason why these castes had different responses to similar climate exposure (Crane, 2010; Adger et al., 2012). We therefor infer that farming strategies, livelihood capitals and culture mutually influence each other, leading to specific development paths and climate change resilience for the HHs in these three farming systems (Fig. 2).

### 4.2. *Development policies in India drive farming strategies of rural HHs*

India's policies have a long-term perspective on climate change adaptation, and the state and district-level programs aligned under these policies could positively influence availability and access to livelihood capitals in the form of schemes, subsidies, or development projects at various aggregation levels. However, several gaps exist. For example, in the study region, we find various development programs (see section 3.2) and market forces that continue to promote green and white revolution practices. These drive agricultural transitions towards highly water-intensive production systems, despite the projected negative climate change impacts for semi-arid regions (see sections 3.3.1 & 3.3.2). The CD system is a classic example of how an outcome of livelihood strategies promoted by development programs increases HHs' vulnerability to climate change exposure, as this farming system is highly sensitive to water and fodder shortages and increasing temperatures (Seo and Mendelsohn, 2007; Thornton et al., 2009; Porter et al., 2015; Rojas-Downing et al., 2017). The presence of such water-intensive farming systems, particularly in dryland regions, poses a risk as it can cause marginalization of a large number of HHs over time due to ground water depletion (Sishodia et al., 2016; Shukla et al., 2019). Furthermore, certain measures of development programs, e.g., conversion of wastelands into croplands, reduce CPRs and change land use patterns, impacting the scope for small ruminant production in the future. Although traditional livestock keepers continue to adapt to such changes, climate exposures in the region exacerbates the existing problems in terms of further loss in vegetation cover in CPRs. Such long-term impacts are often not realized by ongoing state development programs and work out to be counterproductive to national climate change policy ambitions (Dubash and Jogesh, 2014; Adam, 2015; Gajjar et al., 2019; Singh et al., 2019b).

Hence, we highlight that ongoing state-level development programs need re-evaluation not only in the light of climate-related sensitivities faced by rural HHs, but also with regard to the economic and ecological sustainability of current farming systems. Similarly, further research will be required to predict farm development pathways and their short-, medium-, and long-term impacts, as dryland regions are already bio-physically vulnerable ecosystems (Singh, et al., 2019a).

### 4.3. *Research to improve climate change interventions and sustainability of farm development pathways*

Substantial research efforts and development approaches have been undertaken to support climate change adaptation but with limited impact. Wise et al. (2014) attributed this to the lack of a broader understanding of "adaptation pathways." Hence, in this study, we combined quantitative and qualitative research methods to get in-depth insights into adaptation pathways for informed policy making. The use of mixed methods research provided perspectives on how development policies and programs stimulated or constrained farm development pathways, indicating varying short-, medium-, and long-term impacts. Quantitative research gives insight in the relative importance of phenomena, while qualitative research helps to identify the reasons behind a phenomenon for example farm strategies can be explained by the actual farm situation, while qualitative inquiry indicated the identity and aspirations of a farmer (Crane et al., 2008). Thus, mixed research methods enabled us to get a more holistic perspective on how certain trends evolve and why. We therefore recommend using mixed methods to understand the contextual nature of adaptation and help fine-tune adaptation policy and execution at the local level.

## 5. Conclusion

The present study aimed to enhance our understanding of the mutually influencing farming strategies, farm development pathways, and associated climate change vulnerability of three smallholder farming systems in the study region, namely, (i) crop without livestock (CWL), (ii) crop with small ruminants (CSR), and (iii) crop with dairy (CD) systems. The mixed methods research enabled us to understand the contextual nature of HH-level adaptation. The study shows that HHs belonging to different farming systems face differential vulnerability due to variations in perceptions of and sensitivity to climate change exposures and access to livelihood capitals. The CWL HHs system were highly vulnerable to increased maximum temperature and erratic rainfall. These factors affected crop farming and hindered their ability to take up wage work for long hours. However, HHs in the CD and CSR systems were more vulnerable to the overall reduction of precipitation as it affected grazing possibilities and water resources for their livestock.

Though climate exposure was felt by HHs in the region, we found that market forces for cash crops and specific animal products and the accessibility of livelihood capitals provided by development programs highly influenced farming strategies. Consequently, HHs of different farming systems followed different development pathways and had different levels of climate change resilience. Among the three farming systems, the CWL system HHs had the least access to all livelihood capitals and hence showed the highest vulnerability. Their farming strategies only enabled to cope, meeting immediate needs at the expense of long-term resilience. In the CD system, HHs had access to all critical capitals, which facilitated them to opt for more sustainable farming strategies. However, these farming strategies will only last as long as HH can benefit from their boreholes, extracting non-renewable water resources; hence the adaptation is not sustainable in the long run. The CSR HHs belonged to a specific ethnic group. This identity and traditional knowledge made them opt for low-risk farming strategies, leasing lands, and water resources for a modified small ruminant production and supporting long-term adaptation.

From the social group perspective, we found the HHs belonging to SC group and those with small farms were mainly present in the CWL system and also most vulnerable. The ethnic identity and traditional knowledge played a key role in selection of farming strategies and adaptation pathways for the ST - *Banjaras* and BC – *Gollas*. In terms of gender, we found that men and women have similar perceptions of exposure but are impacted differently. Climate change tends exposes women more to exiting issues from transition and feminization of agriculture, while social norms prevent them to apply critical adaptation strategies.

Lastly, the case study showed that despite the integrated climate change policy at the national level, state-level development programs show a misalignment, as they focus more on agricultural intensification rather than climate change adaptation. This situation stimulates farming strategies that are lucrative in the short term but endanger farming system resilience in the long term. Therefore, we recommend policy makers to give high priority to climate smart development, in close attunement of state development programs, and science-based evaluations of these programs if they aim to achieve economic development and climate change adaptation objectives in dryland regions. In the future, contextual studies that bring in more understanding of entwined farming development pathways of various dryland farming systems are warranted.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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